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TNO report

TNO-DV 2006 A450

Satellite Applications for Military Support

Trendwatch from an EO perspective

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Satelliettoepassingen voor Militaire Ondersteuning

Trendwatch vanuit een EO perspectief

Probleemstelling

Een veilige, effectieve en efficiënte uitvoering is wat telt tijdens expeditionaire taken van de Nederlandse strijdkrachten in afgelegen gebieden in de wereld. Deze gebieden zijn veelal kustwateren en desolate bergachtige omgevingen in het Nabije Oosten, Afrika en het Midden Oosten; daar waar de meeste taken liggen voor Nederland binnen NAVO- en UN-verband in joint tasks. De weer- en atmosfeercondities die actueel zijn voor de regio creëren vaak onverifieerbare en onvoorspelbare factoren die tactische en strategische beslissingen op een nadelige manier kunnen beïnvloeden. Een scala aan natuurlijke en kunstmatige condities is te benoemen die de uitvoer van operaties kunnen bemoeilijken. Een snelle inschatting van de omgevingscondities door de juiste informatie is dan vereist.

Beschrijving van de werkzaamheden

Binnen het kader van programma V509 'Omgevingsinvloeden op sensor- en wapensystemen' is een verkenning gedaan naar de mogelijkheden om data van elektro-optische satellietsensoren toepasbaar te maken voor militaire ondersteuning.

Toepasbaarheid

De operationele eenheden van de krijgsmacht zijn afhankelijk van de correcte meteorologische voorspellingen die worden aangeleverd door de gebruikelijke kanalen van de meteodiensten. Andere weereffecten en onvoorspelbare condities en fenomenen zijn echter vaak moeilijk snel in te schatten en worden meestal niet meegenomen in de planning. Als *in situ*-data niet of zeer beperkt voor handen is, zoals in onherbergzame gebieden, zijn remote-sensingdata (en ook modeldata) een uitkomst. Satelliettoepassingen komen voor tactische en strategische planning steeds meer in de schijnwerpers te staan. Bij TNO Defensie en Veiligheid wordt voor radartoepassingen vooruitgang geboekt in o.a. de ontwikkeling van omgevingsproducten voor 'image intelligence'-ondersteuning.

PROGRAMMA	PROJECT
Programmabegeleider drs. W. Pelt, Koninklijke Marine	Projectbegeleider drs. W. Pelt, Koninklijke Marine
Programmaleider Prof. dr. A.M.J. van Eijk, TNO Defensie en Veiligheid	Projectleider dr. R.M. Schoemaker, TNO Defensie en Veiligheid
Programmatitel V509 'Omgevingsinvloeden op sensor- en wapensystemen'	Projecttitel V509 Satellieten Trendwatch
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Toezichthouder dr. M. Leeuw	
Frequentie van overleg Met de programma/project-begeleider werd 1 maal gesproken over de invulling en de voortgang van het onderzoek.	Projectteam dr. R.M. Schoemaker, TNO Defensie en Veiligheid

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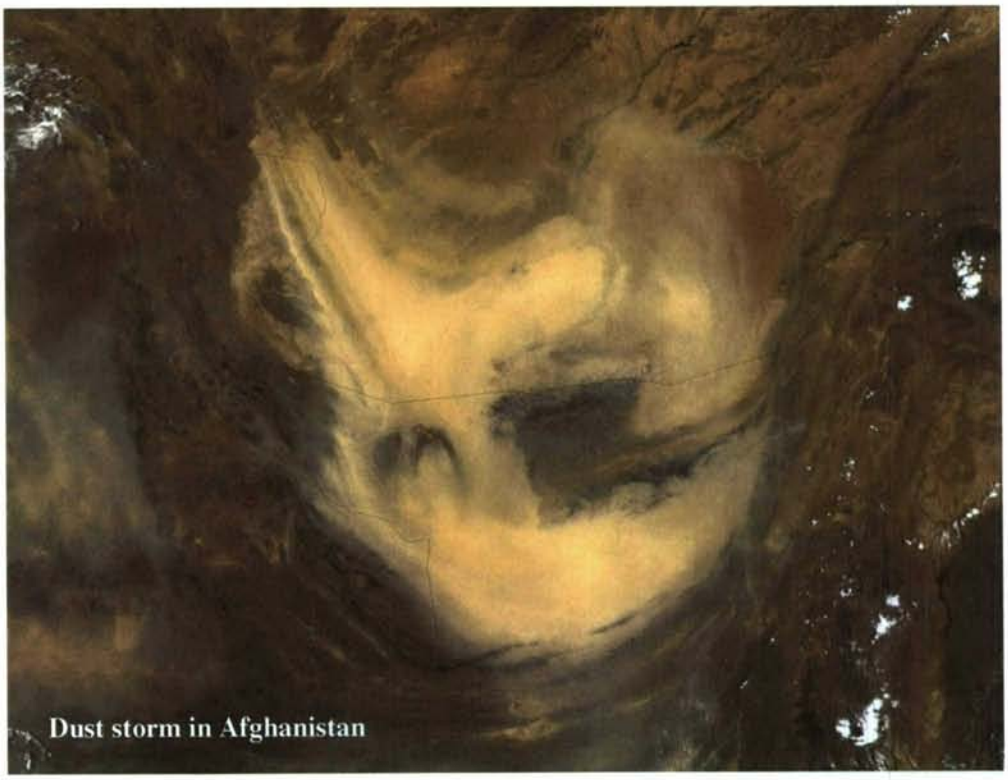
1 Introduction

1.1 Problem definition

The expeditionary tasks of the Dutch Armed Forces are performed in the waters of coastal regions and on land in desolate, rural regions. The local weather and atmospheric conditions are unpredictable factors that often influence tactical and strategic decisions. This can lead to diversion and/or interruption of land, air and naval operations. The atmospheric effects that render sensor, weapons and communication systems inoperable can also cause calamities with potential victims and material damage.
The environmental conditions predetermine a safe, efficient and effective deployment of forces, whereby an accurate assessment of information on these conditions is required. Many operations take place in regions where the infrastructure is in a bad shape or not present at all. If *in situ* data is not or only limited available, operational data retrieved from model data and/or remote sensing data is required.


Dust storm in Afghanistan

1.1.1 Natural phenomena

When dust (fine sand and other tiny granular material) is blown upwards to hundreds of meters (and even kilometres) in height, and is stretched out along hundreds of kilometres above land and sea, it creates a condition in which sensor and weapon systems are ineffective. Inside these storms visibility will be reduced from tens of meters to zero, such that laser guided weapons are rendered useless and targets can no longer be detected. These dust storms also pose a threat to helicopter pilots as the storms can cause damage to the engines of low-flying aircraft, which in turn could lead to potential casualties. Other problems might occur with communications and logistics.

Dutch F16 pilots, for example, frequently operate in Afghanistan where they patrol the airspace over its capital, Kabul. Fuel provision takes place by flying in a KDC-10 tanker aircraft from the RNLAF base Eindhoven. In case of a sudden large-scale dust storm – which is not rare in that part of the world – the tank operation could not be prepared for in time and is to be stopped when the dust reaches high altitudes. Consequently, the KDC-10 will return back to Europe where it will be likely replaced by a more expensive commercial tanker. Dust events cannot be predicted even if meteorology data are known through the usual weather service. In addition to dust storms, strong convective clouds with accompanying heavy rainfall and wind shear form unwanted weather dynamics for air operations. Other atmospheric conditions and weather effects that are undesirable in most military operations are big (smoke) plumes, aerosol distributions, fog, snow, and ice accretion, etc.

1.1.2 *Artificial phenomena*

In addition to the direct environmental effects mentioned above, there are other phenomena that are of interest. Artificial features that can be seen in the skies and waters on a global scale are the marks that aircraft and ships leave behind. These contrails from aircraft and ship tracks from ships are artificially produced clouds with distinctive linear and sometimes curved characteristics. Ships also leave their tracks as ship wakes in the surface waters. The interaction of man-made vehicles with the environment creates conditions that can be monitored. Under the right atmospheric and weather conditions, direction, height and speed can provide the necessary intelligence for tactical and strategic decisions.

1.1.3 *Examples from U.S. missions*

There are numerous examples from realistic situations in the field. For example, in reference to the dust problem, during Operation Enduring Freedom (OEF) in Afghanistan and during Operation Iraqi Freedom (OIF) in Iraq it has been demonstrated that applicable satellite products are of great benefit for operational tasks. An excerpt from an officer on board a U.S. aircraft carrier in the Northern Arabic Sea (NAS) reads:

> "*While operating in the NAS in support of OEF, the primary METOC-related impact to operations was decreased visibility in northwest and southern Afghanistan ... In one case, the extent of the suspended dust ranged well out into the NAS, with visibility less than one nautical mile.*" [from S.D. Miller, 2003]

A more dramatic example concerns an excerpt from communications between METOC (Meteorology/Oceanography) staff on board a U.S. aircraft carrier and scientists of the Naval Research Laboratory (Monterey, USA). Here a dust front reaches the fleet and reduces visibility to zero implying that aircraft must land as soon as possible to prevent additional calamities. The necessity of the right intelligence in a small time frame - the products in the excerpt - is clear:

[U.S.S. Abraham Lincoln (CVN-72); 25 May 2003] "Navy ships are taking over all operations in support of ground troops and bomb runs. The Air Force has stopped operations. All ships are receiving aircraft from others as well. We are currently using the products to determine the Abe's track to safely support the mission" [S.D. Miller et al. 2004].

Also:

> *"Your product was invaluable – we were able to track the progression of dust through southern Iraq and Kuwait. This enabled us to coordinate with AIROPS and move to diverted fields. – AG1 Glenn, USS Nimitz (CV 68)."*

These three examples highlight the fact that the U.S. Navy and the U.S. Air Force require adequate information on atmospherical and meteorological conditions to anticipate well on all fleet and aircraft movements during drills, peace and war missions, and to stay effective in defense and strike power concerning all relevant sensor, weapons and communication systems.

1.1.4 Problem definition

A safe, efficient and effective deployment of forces is what matters during expeditionary tasks. When operating in difficult circumstances, the Dutch Armed Forces depend on the meteorological forecasts that are delivered through the usual METOC channels. However, an accurate and rapid assessment of other weather effects and of unverifiable and unpredictable atmospherical conditions and phenomena, both natural and artificial, is difficult yet critical, but often not taken into account. Remote sensing of most of these phenomena with space-based instruments has become a promising discipline for tactical and operational purposes. This report will elaborate on the applications of satellite data that provide the relevant information of the environment, with a focus on state-of-the-art U.S. initiatives.

1.2 Operational U.S. programs

After September 11, 2001 the Office of Naval Research (ONR) of the U.S. Department of Defense initiated a program that since then has demonstrated the strength of satellite retrieved information on natural and artificial effects due to weather and atmospheric conditions to support expeditionary military tasks all over the world. The *Satellite Focus* program delivers the U.S. Department of Defense with operational environmental products acquired from data from 20+ satellite instruments among which are instruments (e.g. OLS) from the Defense Meteorological Satellite Program (DMSP). The success of Satellite Focus resulted in a civil spin-off program called *NexSat* that

offers a similar range of informational products for the North American continent only and which is publicly accessible through the internet.

1.2.1 *Satellite Focus*

Paragraph 1.1.3 mentioned the use of products to determine a safe track for an aircraft carrier during harsh environmental conditions. These are the actual operational products based on near real time (NRT) satellite data delivered by FNMOC (Fleet Numerical Meteorology and Oceanography Center) through the Satellite Focus program. FNMOC is the heart of METOC (Meteorology/Oceanography) operations for the U.S. forces and delivers meteo products on an hourly basis. Satellite Focus is led by the Marine Meteorology Department at the Naval Research Laboratory (NRL) in Monterey, U.S. and aims at delivering METOC staff with value-added tactical satellite products on atmospheric conditions for important strategic and tactical regions in the world. Satellite Focus is implemented by means of a fully dynamic demonstrator with a web-based interface. A user can zoom in on a world map for a specific region of interest and can further zoom in to a certain degree of resolution – depending on the product and choice of satellite instrument. Then from a suite of tactical products the necessary situation is quickly and efficiently presented graphically. Substantial effort is put into the delivery of the products through secure internet protocols. The infrastructure within Satellite Focus for this delivery depends on close collaboration between agencies like NASA, NOAA, NRL and DoD (FNMOC). Some products can be delivered within 15 minutes to the U.S. METOC officers around the world.

1.2.2 *NexSat*

The success of Satellite Focus resulted in a public program that demonstrates the use of satellite derived products covering the U.S. continent. The Naval Research Laboratory's NexSat webpage* offers the public a fascinating glimpse of the National Polar-orbiting Operational Environmental Satellite System (NPOESS) era. The NPOESS satellite converges existing polar-orbiting satellite systems under a single national program; it is a satellite system to monitor global environmental conditions, and collect and disseminate data related to weather, atmosphere, oceans, land and near-space environment. NPOESS is the next generation satellite program for U.S. Earth observation purposes and is the cost-effective collaboration between the Department of Defense and civil agencies. The NexSat initiative previews tomorrow's operational weather satellite imaging capabilities on NPOESS using a consolidated suite of sensors from advanced technology research and operational environmental satellite constellation. A user-friendly interface with online tutorials guides users through a collection of value-added imagery products created in near real-time over the United States. Some of the same cutting edge applications serving U.S. Forces overseas with Satellite Focus can now provide U.S. communities with practical weather updates in their own backyards.

1.3 Prospect for TNO and the Netherlands Ministry of Defence

The unique innovative services and operational products that FNMOC and NRL deliver with Satellite Focus are dedicated for use by the U.S. armed forces only and are not fully available to third parties. The NexSat initiative, however, is publicly accessible, yet only covers U.S. soil and is not operational within a military context. However, much can be learned from both programs; they are state of the art and show some future

* http://www.nrlmry.navy.mil/nexsat_pages/

prospects of American developments in satellite programs, innovative software, hardware and operational design dedicated to satellite applications for meteorology and atmospheric research.

Although initiatives as Satellite Focus and NexSat are currently not feasible or required for implementation within operations concerning the Dutch Armed Forces, it is important to be able to demonstrate in the (near) future that satellite data contribute to safer and more efficient and effective tasks. At the moment, the Dutch Armed Forces operate in multiple regions in the world and will continue to do so in the years to come. No matter how extensive an expeditionary (joint) taskforce is, weather conditions and atmospheric phenomena will always play a significant role. This is also recognised by NATO in the light of Rapid Environmental Awareness (REA).

> *"The tactical advantage will probably depend not on who has the most expensive, sophisticated platforms but rather on who can most fully exploit the natural advantages gained by thorough understanding of the physical environment." – Rear Adm. W.G. Ellis, U.S. Navy, Oceanographer of the Navy, 1999* [F.H. Vink LTZ2, 2001].

2 Objectives

Future programs for the Dutch Ministry of Defence concerning atmospheric research on environmental effects will be more pragmatic by nature. It is expedient to demonstrate that applied knowledge has added value within an operational context. The following aim has been formulated to provide the guideline for satellite applications:

> *"To make satellite data applicable so that tactical relevant environmental information becomes available in near real time as value-added atmospherical products for the Dutch Ministry of Defence."*

2.1 Context

The Electro-Optics department of Business Unit Observation Systems has expertise in the field of satellite remote sensing of the atmosphere with spectral radiometers. A large part of these research activities has been dedicated to the provision of a number of atmospherical products for air quality and climate studies within the EU and for national projects. A shift to a more military goal has been made recently. The Dutch Ministry of Defence can benefit from this expertise and thus initiatives have started in the program V509 'Omgevingsinvloeden op sensor- en wapensystemen' – see also Subsection 4.3.1.

In 'Technologieverkenning Defensie 2004', TNO-report FEL-04-A144, Chapter 3, paragraph 3.1 'K01 - Sensoren', page 207 the following is stated:

> *"(...) Op dit moment ontwikkelt zich een militair-operationele behoefte, en kan de volgende richtinggevende eisen en aandachtspunten worden geformuleerd:*
>
> - *Adequate waarneming onder alle omgevingscondities, zoals all-weather en all-day*
> - *(...)"*

In 'De Marinestudie 2005', published on October 14, 2005, a package of measures has been summed up that aim at harmonising the means and constitution of the Royal Netherlands Navy (RNLN) for her tasks. An excerpt reads as follows:

> *"(...) Zo moet een patrouilleschip overal ter wereld onder alle weersomstandigheden kunnen worden ingezet en moet het langdurig een groot gebied kunnen bestrijken. De twee laatstgenoemde aspecten verkleinen de voorspelbaarheid van operaties en bevorderen het verrassingseffect van acties. (...)"*

In the TNO 'Operationeel Plan 2006', published on October 18, 2005, Section 4.9 at pages 22 and 23 in paragraph 4.9.9 'Ruimtevaart' states:

> *"(...) Marktmogelijkheden voor Nederlandse bedrijven en organisaties zijn voor een belangrijk deel afhankelijk van investeringen van nationale overheden. Door beperkingen in de Nederlandse bijdrage in*

ruimtevaartprogramma's staat de ruimtevaart markt onder druk. Naar verwachting is marktgroei alleen realistisch in een beperkt aantal sectoren. Hierbij moet gedacht worden aan:

- *Participatie in EU programma's zoals het Galileo en EU Launcher*
- *Versterking van trendsettende technologieën op het gebied van aardobservatie, navigatie en telecommunicatie, inclusief integratie van deze thema's*

Ten aanzien van militaire toepassingen is nagenoeg geen sprake van internationale samenwerking. Vrijwel alle militaire programma's worden derhalve nationaal uitgevoerd. In Nederland is de militaire belangstelling voor ruimtevaart in de laatste 10 jaar sterk afgenomen. Waar Defensie midden jaren 90 nog voor M€ 2 tot 3 per jaar deelnam aan het NRT, is dat inmiddels afgenomen tot 0. Gelet op de nog immer voortdurende bezuinigingen binnen Defensie en de krijgsmachtdelen, is omkering van deze trend niet op korte termijn te verwachten.
Tegelijkertijd echter, is het besef gegroeid dat waarneming, evenals communicatie en commandovoering gediend zijn met "space assets".
In Nederland neemt men dan liever een afhankelijke positie in, waarbij diensten door derden worden geleverd, dan een zelfscheppende positie.
De laatste positie is waarschijnlijk kostbaarder en ook risicovoller dan de eerste.(...)"

In this 'Operationeel Plan 2006' it is highlighted that market growth is realistic for a trendsetting technology like Earth observation. This is not surprising as Earth observation is - besides scientific exploration – a highly successful operational service with and without commercial objectives. Also mentioned is the growing awareness for the use of space assets for observation purposes within the context of military applications.
Although it is commonly thought – according to the last paragraph in the excerpt above - that services provided by third-parties are more cost-effective, this is certainly not trivial, as highlighted in paragraph 1.3.

2.2 Demand and delivery

The relevance of tactical satellite products can be made clear by identifying potential users, requirements, and deliverables.

Potential users: Forecasters and (weather) analysts within the Armed Forces, referring to the METOC service of the Hydrography Service (Dienst der Hydrografie) of the RNLN and the Air Force Meteorology Group (Luchtmacht Meteorologische Groep, LMG) for the Royal Netherlands Air Force (RNLAF) and Royal Netherlands Army (RNLA).

- The METOC service of the RNLN is part of the Hydrography Service (Dienst der Hydrografie) and provides the Navy with up-to-the-minute information concerning meteorology and oceanography for the support of military operations.
- The Air Force Meteorology Group (Luchtmacht Meteorologische Groep, LMG) acts as central weather service for all air bases, deployed detachments, RNLAF Air Operations Control Station (including military air traffic control), the RNLA and NATO. LMG provides these groups 24 hours a day with up-to-date weather

information and with short and long term forecasts. LMG is closely associated with the operational usability of people and materiel.

See also paragraph 4.2.

Requirements: Easy accessible, comprehensive yet easy to interpret graphical products for quick analysis of salient tactical information.

Solutions: Post-processed multi spectral, multi sensor and/or model fusion data by means of dedicated algorithms or efficient software suites and models in order to expose the underlying physical phenomena presented as value-added products.

The challenge: To make available (near) real time satellite products that describe up-to-date and predictable environmental conditions of the atmosphere in the region of interest.

3 Tactical environmental products

Tactical environmental products are value-added products of environmental conditions represented as graphical presentations for quick analysis of salient information on physical phenomena in the planetary boundary layer, the oceanic and coastal waters and on land. The products are accessible through an efficient interface and are extracted from satellite data by means of dedicated algorithms and imaging software. They can be combined with model data or can be used as input for models. In short:

> *Tactical environmental products minimise interpretation time and maximise information content.*

In Section 1.3 the notion of Rapid Environmental Awareness (REA) was put forward. Information content as defined above is immediately recognised within the REA concept, which is a challenging development of information gathering and presentation of environmental conditions for military joint tasks.

The remainder of this chapter enumerates a suite of potential products that have both natural and artificial features. The images shown in the following paragraphs are often depicted as true colour images and are shown here to underline the nature of the phenomenon; they are not the products in the sense of the definition given above. These products have not been developed yet, with a few exceptions that carry the TNO logo or examples obtained from the NRL Satellite Focus and/or NexSat developments. A final future value-added product is obtained by image enhancement techniques and algorithmic applications on data from several satellite instruments. It reveals the underlying physical features that are often not recognisable in true colour imagery.

3.1 Dust storms

The introductory chapter of this report highlights the example of dust storms as they thrive in domains of recent conflicts in the Middle and Far East, and pose a major problem to expeditionary operations. Vast areas of desert like soil and dry mountainous terrain can influence the environmental conditions by creating clouds of sand that reduce visibility for pilots, damage jet engines and helicopters, and render laser guided weaponry ineffective. Military operations of allied forces have encountered this atmospheric phenomenon more than once, resulting in the postponement or cancellation of a mission.

Dust consists of solid sand granulates with sizes up to 300 μm. Once suspended in the air – depending on the meteorological conditions – accumulated dust can be transformed into an extensive and massive floating wall of sand. In order to track this phenomenon from outer space, dust detection algorithms are required that process the data from satellite instruments. True colour imagery from space-based instrumentation is able to reveal dust storms over waters and sometimes over land (see the image in paragraph 1.1). However, often these storms can hardly be distinguished over bright desert like areas. Dedicated algorithms that use specific spectral features of the data can identify and discern a storm quickly and efficiently. A good example is given in Figure 3.1.

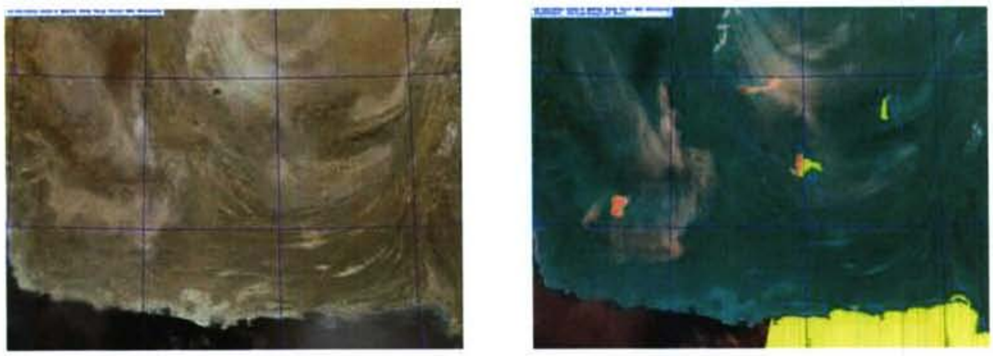


Figure 3.1 Example of a dust product from the U.S. Satellite Focus program. It can be difficult to distinguish between dust and bright reflecting ranges of rock, as can be seen on the left panel where a true colour image shows two dust storms above land somewhere in the Middle East. A dust detection algorithm quickly discerns the features of the land and the atmospheric condition of the environment in the right panel. The dust storms are pink in colour.

3.2 Plumes

Plumes in the planetary boundary layer (up to approx. 1000 meters) are numerous. The plumes in the context of this document are of substantial size, in the order of 0.1 to 100+ km in length and in a certain direction. They can have a natural as well as a human cause. Ash and smoke plumes from volcanic eruptions, dust plumes in desert areas, smoke plumes from hotbeds caused by lightning, are examples of plumes with a natural cause.

Figure 3.2 The left true colour panel depicts part of the Iberian peninsula. The huge forest fires in Portugal spawn large plumes of smoke extending over the Atlantic Ocean. The right true colour panel shows very long black smoke plumes caused by several oil fires in Kuwait during the first Gulf War. Images by courtesy of NASA.

Human errors, however, can cause huge forest fires, such as the returning fires in Portugal each year (Figure 3.2). Large plumes that are caused deliberately are the soot plumes of oil fires (for example during Gulf War I – Figure 3.2; right panel) and large fires on land (forest, buildings). Huge vessels at sea that have caught fire can produce plumes that extend over hundreds of kilometres and which are clearly visible from space. The effect of these plumes on military operations can be enormous. Large-scale smoke plumes from oil fires, volcanic eruptions or other soot forming hotbeds, can reach very high altitudes and are disastrous for aircraft engines and therefore extremely dangerous for helicopter operations. Soot and ashes cause reduced visibility for the

extended area where the plume originates, but can also cause serious health problems for local people and patrolling troops.

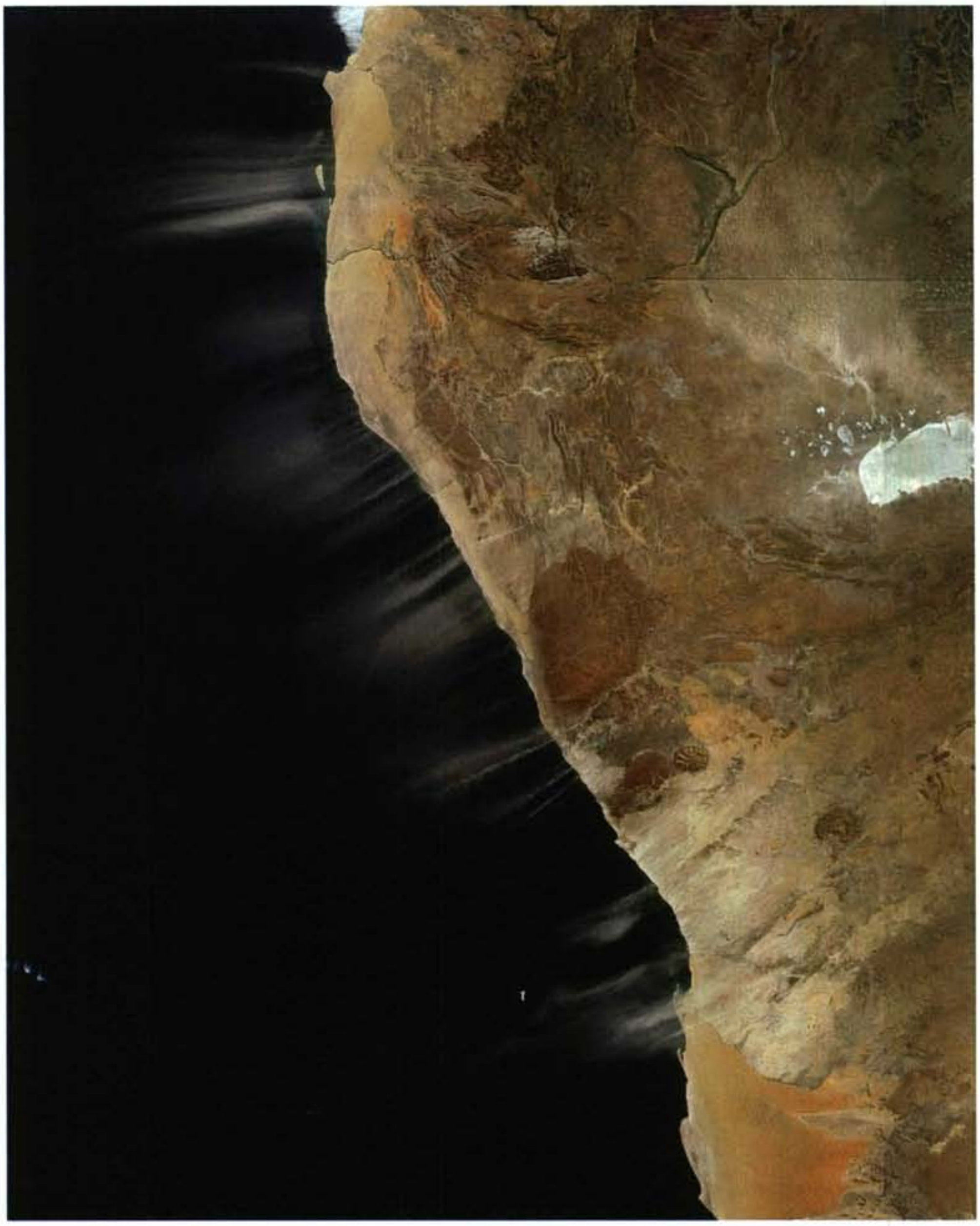


Figure 3.3 Plumes of upward blown dust from the West African coast extend tens to hundreds of kilometres over the Atlantic Ocean. These plumes are a problem for patrolling Navy vessels and low flying aircraft and/or helicopters. True colour image from NASA.

On the other hand, plumes of dust particles originate close to the surface and are caused by soil/wind interaction. They are often the cause of the large dust storms mentioned in Section 3.1. Dust plumes have an elongated shape that shows the direction of the wind and they manifest themselves on smaller time scales than smoke and ash. Dust plumes are a major problem for sensor and weapon systems on board naval vessels and for troops operating in the littoral. A clear view from outer space on the dust plume phenomenon is given in Figure 3.3.

Detection of large plumes is useful from an operational point of view. A valuable plume product should clarify the nature of the plume (dust, smoke, ash), assess the cause of the plume (natural or human), but also estimate the height and the direction of movement of the plume. The time frame should be small for a plume product and meteorological information is indispensable in this perspective.

Smaller plumes from chimneys, from small hotbeds[†] and other sources also pose problems for sensor and weapon systems. However, the resolution of most (optical and infrared) Earth observation instruments is not satisfactory. An operational area of only tens of meters is not foreseen within the context of this report, but note that the American Quickbird and the French SPOT satellites have resolutions of several meters to 15 cm. Unfortunately, these instruments have a limited spectral resolution and a very poor temporal resolution. Moreover, data from these instruments is very expensive, in contrast with data from Earth observation platforms that are accessible due to collaborative programs initiated by NASA and ESA.

3.3 Contrails and ship tracks

Contrails (*condensation trails*) of aircraft and tracks of ships are linear or curved structures in the atmosphere. A high-altitude jet condensation trail is a climatologically important by-product of air traffic because it can function as a man-made cirrus cloud (a thin, high-altitude ice cloud). A contrail forms when a combination of hot and humid air and minute exhaust particles from the jet engine mixes with the colder and drier air in the upper troposphere through which the airplane passes.

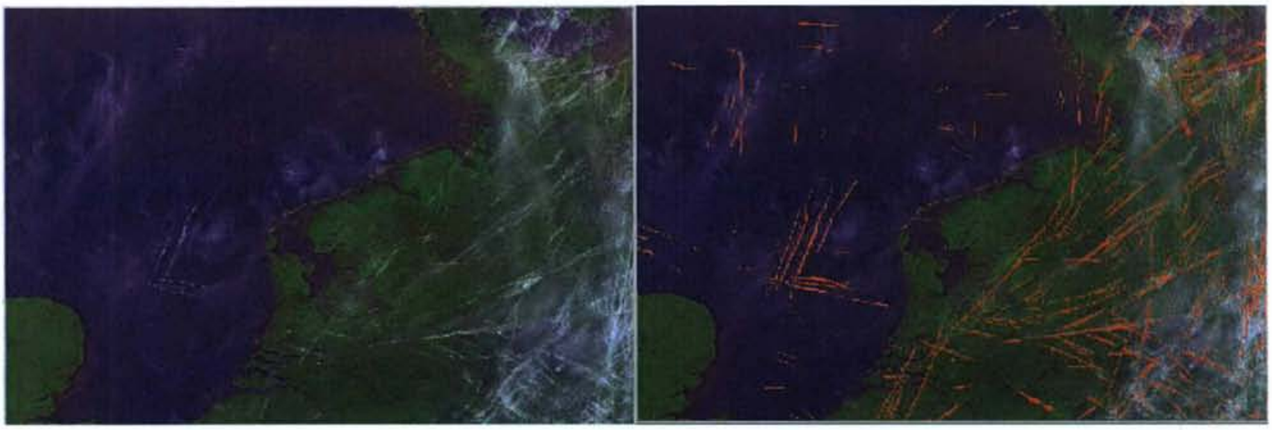


Figure 3.4 A NOAA-12 satellite image from 4 May 1995, showing a high concentration of contrails over central Europe. This image is a product from the current European Space Agency program CONTRAILS. Courtesy: Hermann Mannstein, DLR.

If the relative humidity of the high-altitude air is very low, a contrail quickly dissipates. Is the air moist enough, then the contrail spreads horizontally and forms a thin layer of cirrus cloud that persists for many hours with an average width of 2 - 3 km. Widths of 5 - 30 km have also been observed in satellite imagery. The very small exhaust particles are called condensation nuclei because they attract water molecules and form droplets through an accumulation process. In case of aircraft this process takes place in the upper troposphere at 8 to 13 km height, but it can also occur lower into the troposphere during landing and take-off procedures. Contrails are very noticeable over water as well as

† The source of smoke is often a hotbed, manmade or caused by lightning. Hotbeds form another value-added satellite product – see paragraph 3.8.

over land in true colour high resolution satellite imagery – see for example Figure 3.4. However, contrails are artificial clouds (with cirrus like properties) and become more difficult to detect if natural clouds are present. By using certain wavelengths of the satellite radiometers in dedicated algorithms with image enhancement techniques, contrails can still be made visible. This is shown in Figure 3.5, which gives an example of detection of contrails in a satellite image over France, made with the European satellite instrument AATSR.

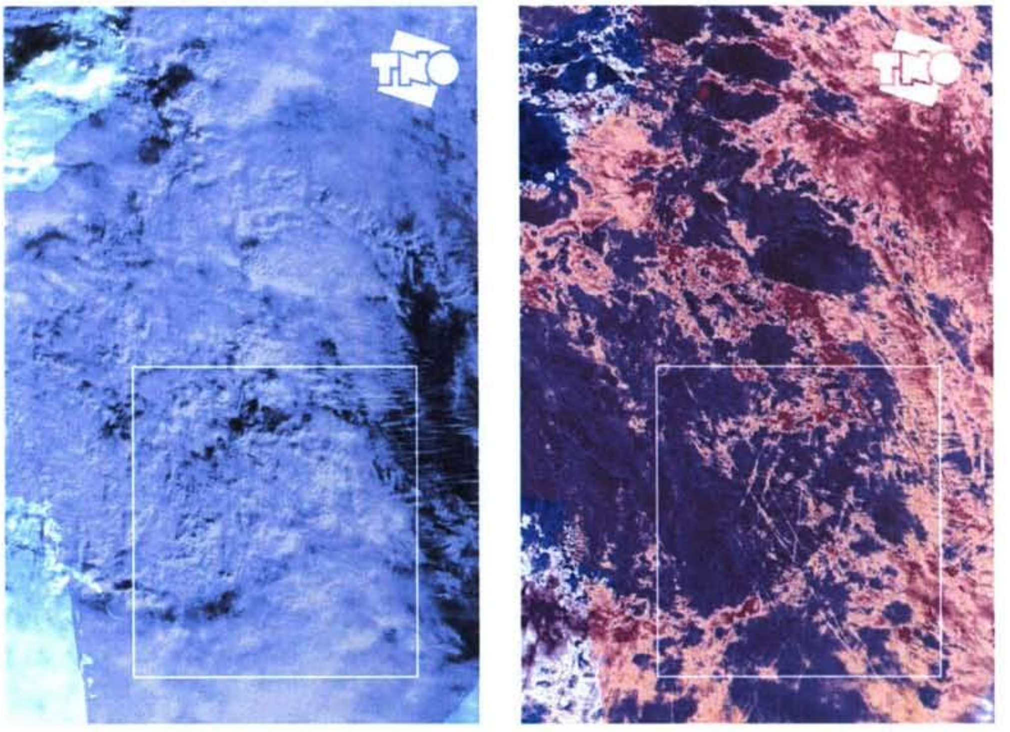


Figure 3.5 An AATSR contrail detection for a scene of 512 × 780 km above France. Contrails are not visible in the left panel where the 0.55 μm visible channel shows many clouds. The same scene is depicted in the right panel, yet by making use of the 11 μm and the 12 μm infrared channels, combined with image enhancement techniques, contrails appear as long, thin linear features crossing each other. The big purple spots are high cirrus clouds, also difficult to discern in the left panel. The resolution is 1 × 1 km. Images made by TNO Defence, Security and Safety.

A ship track is an elongated white streak that is formed in the lower planetary boundary layer and which can be monitored with space-based instruments. These so-called narrow stratus clouds are produced by the small particles in exhaust plumes from the propulsion systems of large vessels. The fuel exhaust particles are smaller than the natural condensation nuclei of normal clouds, resulting in artificially produced cloud droplets that are smaller than the natural droplets. See Figure 3.5.

The air in the lower planetary boundary layer is more turbulent, therefore ship tracks are subject to more erratic meteorological conditions. Contrails, on the other hand, are produced high in the atmosphere in stratified layers of relatively stable air. Both contrails last for hours. Ships, however, move slowly and their cloud tracks are more curved and subject to wind direction. Clues about the speed of the ships can be assessed by looking at the width of the streaks. A narrow long ship track indicates a faster ship compared to short white streaks that are broader. Like contrails, ship tracks are not always visible, not in the least when severe weather with strong winds and turbulent

waters control the atmospheric condition in the region. In Figure 3.6 an example of ship tracks imagery is given.

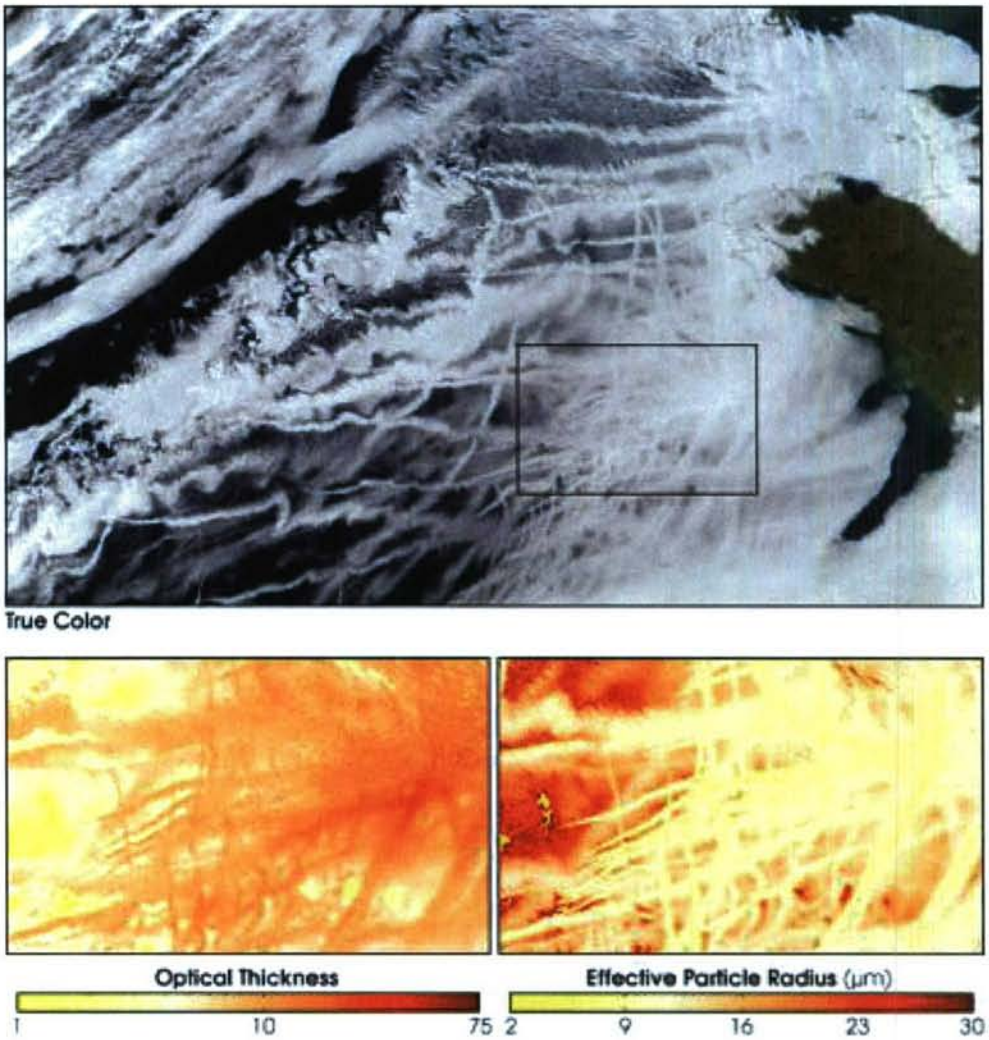


Figure 3.6 Ship tracks in true colour over the Atlantic Ocean with on the right parts of the coast of France and Spain. The image is taken by the American MODIS instrument on board the AQUA satellite. The selection shows the optical depth and the particle radius. Ship track cloud droplets have small radii. The atmospheric conditions in the boundary layer are such that many particles also form many cloud droplets. Image courtesy: Jacques Descloitres, MODIS Land Rapid Response Team and Mark Gray, MODIS Atmosphere Science Team, both at NASA GSFC.

When ships traverse the oceans they also mark their presence by leaving tracks in the water behind them. These so-called ship wakes are v-shaped tracks in the water as a result of water displacement and are only present and detectable if the ocean is calm.

The space-based monitoring of the interaction of man-made vehicles with the environment is of interest from a military perspective. The trails explained above are indicators of the movement of vessels at sea and aircraft high in the sky, and are especially useful when activities take place in regions where radar data (tracking and transponder data) are not available (intentionally or unintentionally). Moreover, not only the contrails are of interest in this view. The spraying of very small particles from canisters suspended under high flying planes with the intention to alter the biosphere of

the region of interest requires special attention. A frequent application is the seeding of the atmosphere above very dry regions in the world in order to create saturated clouds for the production of rain to fertilise the soil beneath. A war-minded or terrorist use of this application falls within the context of chemical or biological warfare. It is also noted that these airborne particles have similar condensation processes – if hygroscopic in nature – and will show up in the sky in the same manner as contrails.

3.4 Aerosol

Atmospheric aerosol is the designation for a suspension of very small particles in air with particle sizes in the order of 0.01 – 100 μm. Aerosol has natural as well as anthropogenic causes. Naturally produced aerosol contributes the most to the global budget. Examples are the smoke of biomass burning, sea salt, volcanic ash (sulphates) and desert dust in all sizes and compositions. Human activities produce particles as well, like soot from the burning of fossil fuel, but also from biomass burning. Sulphates and nitrates from industrial and agricultural activities can be found close to urban areas and most of these anthropogenic produced particles are characterised as polluting aerosol in air quality studies. Aerosol can be transmitted into the atmosphere directly (primary aerosol), but also indirectly by means of gas-to-particle conversions (secondary aerosol). The very small aerosol particles act as cloud condensation nuclei for the formation of clouds, which is an important topic in climate studies.

The products in the former paragraphs, such as smoke, dust, etc., are aerosols, yet the product definition concerns the detection and physical conditions on a larger scale, like height and direction for quick operational analysis. In this, they differ from the aerosol products given in this paragraph.

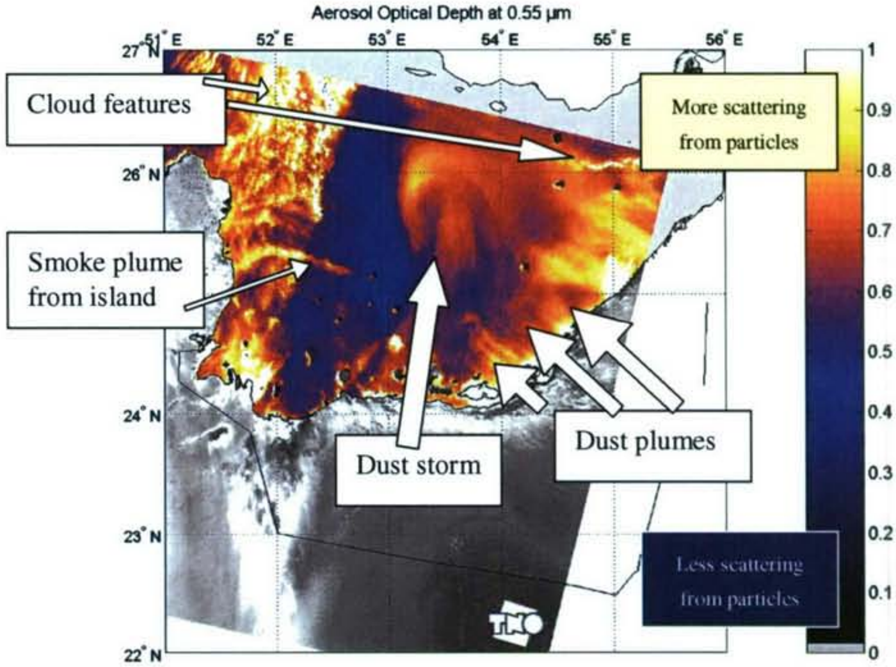


Figure 3.7 The Aerosol Optical Depth for 0.55 μm over water on September 7, 2004 during the United Arabic Emirates Unified Aerosol Experiment. Part of the Persian Gulf is visible. Many atmospherical features are visible, like clouds, smoke, dust plumes and a dust storm – all aerosols. The AOD product has been obtained by using a dedicated retrieval algorithm that uses a two-type modelled aerosol mixture to be compared with the signal at the satellite sensor. The AOD can be retrieved for four wavelengths and indicated the amount of scattering (in this case, as only scattering aerosol types have been modelled).

Three aerosol products are aerosol optical depth (AOD), Ångström coefficient α and aerosol extinction coefficient σ. The AOD is the column integrated extinction by scattering and/or absorption and is a measure for the amount of particles in the atmospheric column between ground surface and the satellite sensor at the top of the atmosphere. The Ångström coefficient α is an indicator for the size distribution of the particles in the column. Finally, the aerosol extinction σ is a measure for the fraction of intensity loss per unit of mixing layer. Examples of the AOD and the Ångström product are given in Figure 3.7 and Figure 3.8, respectively. It concerns a scene of part of the Persian Gulf during the UAE^2 campaign. The AOD and α are obtained by means of dedicated algorithms.

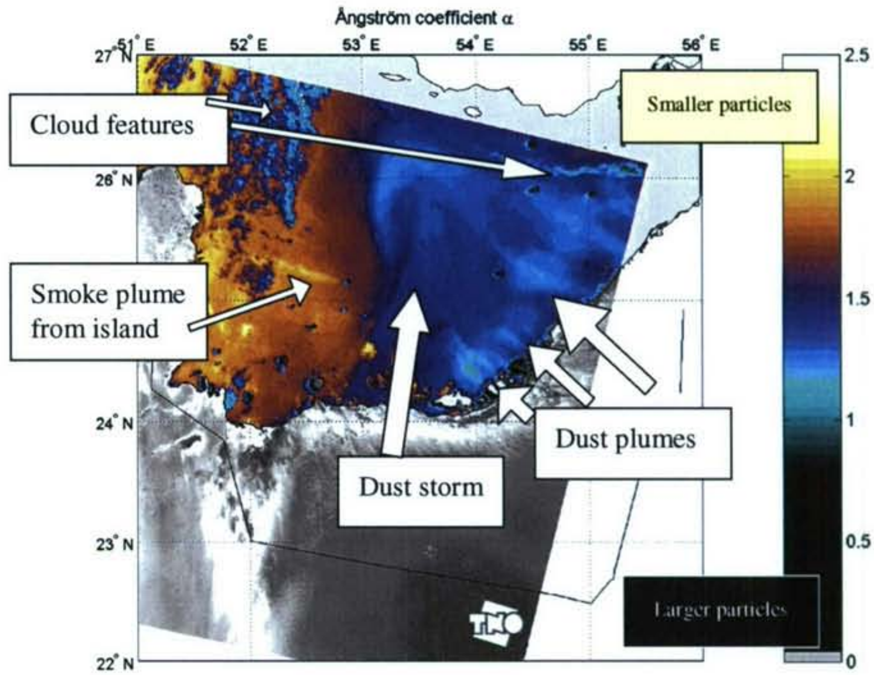


Figure 3.8 The Ångström coefficient α product for the Persian Gulf as in Figure 3.7.

The aerosol extinction σ in the planetary boundary layer just above the sea surface (tens of meters) is an important quantity for the study of transmission losses for detection equipment and for high energy laser weapons. Electro-optical and infrared systems are critical technologies for the RNLN in the detection and neutralisation of high-precision and low-signature anti-ship missiles. An example is the development of a Long-Range Infra-Red Search and Track (LR-IRST) system with detection ranges of 20 to 25 km – a doubling in range compared to the 1990s. Extinction caused by absorption and/or scattering of aerosol and molecular species reduce the contrast ratio of a target with its natural background. Refraction, turbulence and atmospherical extinction from just above the sea surface up to 30 meters high must be accounted for in order to pinpoint the effects that the marine boundary layer has on the detection of point targets at large distances. Small changes in the refractive index by turbulent fluctuations of airflow, air temperature and humidity result in scintillation and beam wander. Variations of the average refractive index with height, due to atmospherical stratification, causes ray bending, i.e., super-refraction, sub-refraction and mirage effects.

Sea salt aerosol, varying in size from approx. 0.01 μm to 20 μm, is an important constituent in the marine boundary layer over oceans and in coastal waters. In coastal areas, however, sea salt particles mix with continental aerosol especially when offshore winds are present. Continental aerosol (natural and/or anthropogenic) has different optical properties than sea salt and the transmission losses for a long path in a coastal environment will differ with transmission losses for sea salt only. Analyses of these situations are important for the study of accurate aerosol model parameterisations. Satellite observations can instantly map aerosol fields with high resolution for a larger region. By using a mixture of two aerosol types in the retrieval procedure, distinction of the types that result in an extinction coefficient σ at a certain height is important for embedment in propagation models.

3.5 Seawater temperature and soil moisture

3.5.1 Sea water temperature

The temperature of the seawater plays a major role in the specification of turbulence properties of the air just above the water surface. Satellite observations are an appropriate means for the acquisition of data for a large area. The sea surface temperature can be used for describing the aerosol extinction along a path just above the water surface, or for determining beam wander along a similar path of tens of kilometres. A clear result can only be obtained if the spatial resolution and the accuracy of a temperature measurement are high enough. An example is given in Figure 3.9 where the AATSR instrument – dedicated for sea surface temperature measurements – shows the high resolution product of the temperature of the surface of the water.

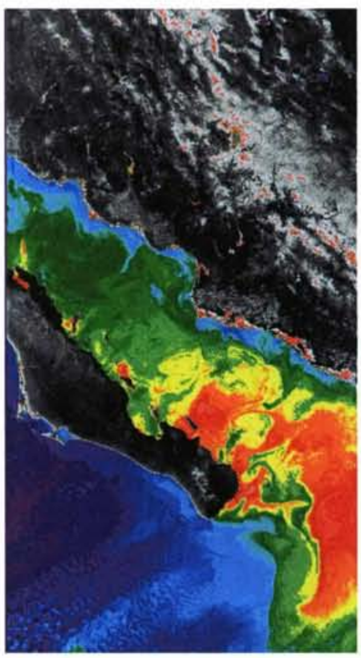


Figure 3.9 The surface temperature of the Baja California waters. The AATSR instrument on board the European ENVISAT platform measures the SST (sea surface temperature) for every pixel of 1 x 1 km with an accuracy smaller than 0.3 K. The temperature range here is 280 - 300 K where red denotes the higher temperature.

Seawater temperature is a valuable satellite product for further study and is interesting from an operational point of view as it can be used as an input parameter for models that compute a propagation forecast.

3.5.2 Soil moisture

Remote sensing of the land surface for moisture levels is of great importance in order to assess the capability of sending convoys through desolate areas. The temperature of the soil is a gauge for the soil moisture if a priori information is at hand on the composition of the land surface.

3.6 Clouds and snow

A cloud product is very versatile and many physical aspects can be enumerated and explained, yet most cannot be directly used in military applications. One potential physical parameter, the cloud top height, will be discussed in this paragraph. In addition, snow and the discrimination between snow and clouds, and between high and low clouds are briefly explained.

3.6.1 Cloud top height

The aviation community depends on knowledge of the height of the tops of deep convective clouds because they can cause hazardous conditions for aircraft flying at high altitudes. The height can be determined by combining the temperature of the high clouds – obtained from satellite observations - with the vertical temperature profile from a meteorological model for the same time and place. In Figure 3.10 a product image is shown that is obtained within the NRL Satellite Focus program using the MODIS instrument. Data is obtained as follows.

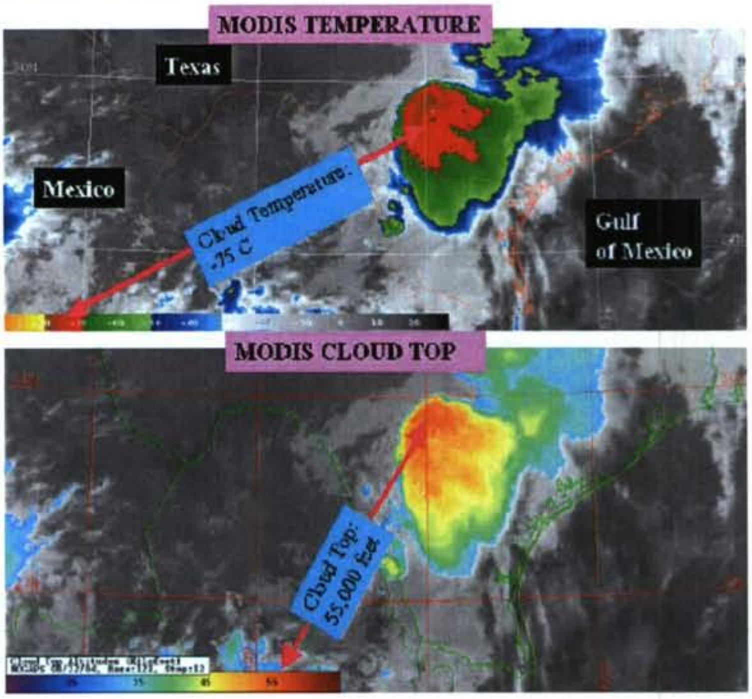


Figure 3.10 Example from NexSat. Top panel shows the MODIS cloud temperature. The green and red colours denote the coldest tops characteristic of deep convective clouds. The arrows show how the temperature of the cloud top can be determined by matching the particular colour of a feature with the colour bar. This is a simple procedure using most infrared images on the internet, but which is not very useful to weather forecasters since they need to know the height of the cloud top, not its temperature. The bottom cloud top image is based on the same data. Here, colour can now be used to depict the actual height. In this case the orange colour corresponds to a height of about 55,000 feet. Source: NexSat, NRL.

Low clouds will be "buried" in water vapour. As the 6.7 μm channel of the MODIS instrument detects the temperature of the cooler water vapour above the cloud (temperature decreases with height), the satellite-measured temperature will be lower than the actual cloud top temperature. The same cloud observed at 11 μm will yield a temperature much closer to the actual cloud top temperature. Therefore, there will be a

large difference between the two measurements (6.7 μm vs. 11 μm). On the other hand, for a high and thick cloud, there is not much water vapour above it to depress the relative difference between 6.7 μm and 11 μm, thus the values in this case are small. Essentially, it is these small differences between the two channels that indicate where the high and thick clouds are.

3.6.2 *Snow/cloud discrimination*

It is important to discriminate between high and low clouds, and between clouds and snow. A value-added graphical representation that instantly discriminates between clouds and snow, however, is extremely challenging and valuable. In addition, in true colour imagery this is often not possible due to the high reflectance and bright appearance in the white colouring. Infrared channels also have difficulty to discriminate between clouds and snow, because of similar temperatures resulting in a poor thermal contrast. The use of many channels from, for example, the MODIS instrument, provides the solution to deliver a product as can be seen in Figure 3.11.

Snow discrimination is highly useful in tactical operations for target identification and target obscuration. Also, military convoys over complex terrain with snow cover and search and rescue operations by pilots in helicopters and low flying patrolling craft that operate in mountainous regions benefit from a quick and efficient assessment of the region of operation.

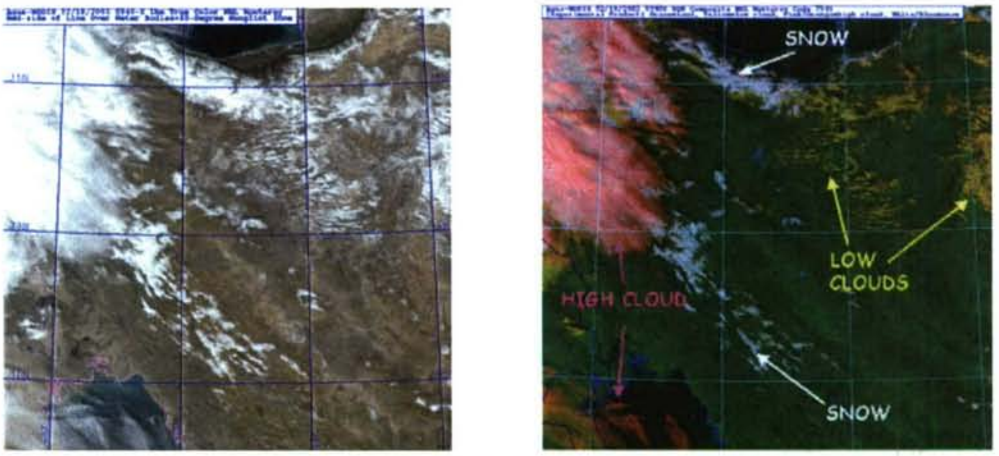


Figure 3.11 Example of the NRL Satellite Focus cloud/snow product that identifies clouds from snow and discriminates between low and high clouds. Source: NexSat, NRL.

3.7 Sedimentation

Sedimentation is a process that takes place along the coast, which concerns the floating and depositing material of sea algae and other small organisms in combination with inorganic material like sand and discharges from sewing systems and other coastal sources. These so-called 'Case-2 waters' are shallow in contrast to the 'Case-1 waters' that are more than 100 km off shore and only have a strong chlorophyll-a component from suspended algae. Satellite observations show that these Case 2 waters reflect the sunlight very well back to outer space. The physical quantity that is often associated with Case-2 waters is turbidity.

The turbid Case-2 waters reduce the visibility, which poses problems for littoral diving operations and for mine hunters. Figure 3.12 depicts a true colour image taken by the European MERIS instrument on board the ENVISAT satellite, showing a sedimentation process on the coast of Bangladesh.

Figure 3.12 True colour image of sedimentation along the coast of Bangladesh. Source: ESA.

3.8 Fires and hotbeds

The detection of fires and hotbeds is an application very well suited for space-based instrumentation. Several existing European and American programs aim for a NRT service of global fire and hotbed detection.

The high resolution AATSR instrument and its predecessor ATSR-2 are equipped with a 3.7 μm channel that can be used perfectly for the detection of hot pixels at night. For AATSR pixels of 1 x 1 km^2 the small fires and hotbeds are spotted depending on the fire temperature, and can be estimated as follows: 0.1 ha at 600K to 0.01 ha at 800K, for a background temperature of 300K.

4 Developments

4.1 Current and (possible) future EO expertise in satellite remote sensing

At TNO Defence, Security and Safety in The Hague the expertise of retrieval of aerosol properties has to large extent been developed within the framework of air quality and climate change studies. These studies are embedded in European and national civil programs and deliver aerosol products to various users in Europe. Aerosol retrieval and especially the determination of the aerosol extinction coefficient for atmospheric propagation research are useful for military satellite applications as well. A recent initiative is currently conducted under Program V509 'Environmental effects on sensor and weapon systems' (see also section 4.3.) The aerosol properties are obtained by running dedicated retrieval algorithms that have been developed in the past ten years. The early algorithms have been applied to data from the ATSR-2 instrument on board the European Remote sensing Satellite ERS-2, which was decommissioned several years ago. The current algorithms are applied to data from the Advanced Along-Track Scanning Radiometer (AATSR) instrument. AATSR is the successor of ATSR-2 and flies onboard the ENVISAT satellite until 2008+ and is a medium resolution radiometer with two viewing angles. The sensor views the Earth with a swath width of 512 km. The height of approx. 800 km (polar sun-synchronous orbit) results in a global coverage once in three days.

AATSR is a polar orbiting instrument with a limited life span. A similar polar orbiting instrument is the NASA MODIS instrument flying onboard the TERRA and AQUA satellites, which has a swath width of 2200 km and thus a global coverage of one day. MODIS, like AATSR, has a finite life time and will be decommissioned in the future.

Geostationary satellites, on the other hand, orbit the Earth at a distance of almost 36,000 km and cover approx. 30% of the Earth's surface instantly. Nowadays they deliver an image every 15 minutes, which is a very high temporal resolution from an operational point of view. Most weather satellites are geostationary for rapid monitoring of global weather. Europe uses the Meteosat operational weather satellites for long duration operation. The U.S. uses the GOES satellites of operational platforms. A synergistic use of polar orbiting and geostationary instruments has proven to be very successful.
A polar orbiter has dedicated wavelength channels for high spatial resolution analysis, whereas the geostationary orbit has certain wavelength channels for high temporal (monitoring) analysis. A good example is the American Satellite Focus initiative (DoD) mentioned in section 1.2 in which MODIS and GOES combined provide most of the required data.

At TNO retrieval algorithms are being developed for the SEVIRI instrument onboard the geostationary weather satellite MSG-1 (Meteosat Second Generation / EUMETSAT). This instrument has only one viewing angle but the same high resolution as AATSR for the visible channels (1 x 1 km^2) and a resolution of 3 x 3 km^2 for the infrared channels. The temporal resolution of one image per 15 minutes is however very good. In 2006 the European EUMETSAT agency launched the first of a series of operational polar orbiting satellites for long duration weather analysis: the MetOp family. ESA's EarthCARE initiative will send the Sentinel family of sophisticated Earth observation satellites into space for the 2005 – 2015 time frame). These two initiatives

will transform Europe into a frontrunner in space-based Earth observation research and operations. The many data that become available are of interest to future applications for military support.

4.2 Potential collaboration

4.2.1 U.S. partners

The Naval Research Laboratory NRL in Monterey, U.S., and the SPAWAR Systems Center in San Diego, U.S. are part of the institutes that have a longstanding collaboration with TNO in relation to aerosol research (sea spray measurements and modeling, satellite retrieval and sensor performance modeling).

4.2.2 METOC (RNL Navy) and LMG (RNL Air Force and RNL Army)

The METOC service of the RNLN is part of the Office of Hydrography and is the platform for Navy METOC operations. The METOC departments are housed in Den Helder, the Netherlands, at the naval airbase De Kooy and also at sea with the squadron staff on board the flagship. Moreover, a METOC team is available for the amphibian transport ship LPD (Landing Platform Dock).

The weather office of the Air Force Meteorological Group (LMG) is open 24 hours a day. The weather service provides weather forecasts and warnings for a large number of military users, among which are meteo offices at operational air bases and expeditionary forces. The IT department operates all equipment - modern communications equipment and sophisticated work stations - for the LMG and the airfields (also for the RNLN), and the equipment for expeditionary tasks during UN and NATO operations ('Out of Area'). The helpdesk fulfils an important role in dealing with and solving complaints of all users of the current workstation METIS 2000. LMG exchanges a large number of weather data with military and civil agencies, both national and international.

Since a few years the LMG houses the department Meteorological Support for the RNLA. This department is closely linked to the department Air Force Meteorological Centre and has been established to provide the RNLA with weather information. There are several (assistant) meteorologists stationed within the Army units.

Future collaboration with these services would be interesting in future geospatial intelligence and geophysical programs.

4.3 Exploration

A first set-up in which satellite applications for military operations are used, is defined in a work package (WP1.1 Satellites) in the current program V509 'Omgevingsinvloeden op sensor- en wapensystemen' (V509 'Environmental effects on sensor and weapon systems') that runs from 1 July 2005 until 31 December 2008. The work package is an initiative concerning the application of satellite products in combination with the propagation model EOSTAR. Its goal is a better assessment of the aerosol extinction along a path of tens of kilometres long, especially in coastal regions, for a height of tens of meters above the sea surface. This work package obviously deals with the value-added aerosol product discussed in Section 3.4.

Exploration of the topics in this report is required as a first start and has been granted funding in the form of so-called 'Kraamkamergeld'. Investigative effort in a so-called 'Kraamkamer project' shall demonstrate whether the new and innovative technology has potential for further development and implementation.

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15. ABSTRACT (MAXIMUM 200 WORDS (1044 BYTE))

A safe, effective and efficient realization is what counts during expeditionary tasks of the Netherlands forces in remote regions in the world. These regions are mostly coastal areas and desolate mountainous terrain in the Middle East and Africa. The current weather and atmospheric conditions for these regions often bring unverifiable and unpredictable factors that influence tactical and strategically decisions in a negative manner. Many natural and artificial conditions can be named that can hamper operations. A fast assessment of the environmental conditions by the right information then is required. Satellite remote sensing data can be of assistance if in situ data is not present in these desolate regions.

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